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T. M. Carlsen, L. E. Paterson, T. M. Alfaro

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MANAGING NATURAL AND REINTRODUCED RARE PLANT
POPULATIONS WITHIN A LARGE GOVERNMENT RESERVATION

Tina M. Carlsen¹

Lisa Paterson¹

Teneile Alfaro¹

¹Lawrence Livermore National Laboratory

7000 East Avenue

Livermore, California 94550

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ABSTRACT

California is home to many large government reservations that have been in existence for decades. Many of these reservations were formed to support various Department of Defense and Department of Energy national defense activities. Often, only a very small percentage of the reservation is actively used for programmatic activities, resulting in large areas of intact habitat. In some cases, this has benefited rare plant populations, as surrounding lands have been developed for residential or industrial use. However, land management activities such as the suppression or active use of fire and other disturbance (such as fire trail grading) can also work to either the detriment or benefit of rare plant populations at these sites. A management regime that is beneficial to the rare plant populations of interest and is at best consistent with existing site programmatic activities, and at a minimum does not impact such activities, has the best potential for a positive outcome. As a result, some species may be “difficult” while others may be “easy” to manage in this context, depending on how closely the species’ biological requirements match the programmatic activities on the reservation. To illustrate, we compare and contrast two rare annual plant species found at Lawrence Livermore National Laboratory’s Site 300. Although several populations of *Amsinckia grandiflora* have been restored on the site, and all populations are intensively managed, this species continues to decline. In contrast, *Blepharizonia plumosa* appears to take advantage of the annual controlled burns conducted on the site, and is thriving.

Key Words: rare plant populations, government reservations, *Amsinckia grandiflora*, *Blepharizonia plumosa*

INTRODUCTION

Both the Department of Defense and the Department of Energy own and operate numerous large reservations in a variety of habitats across the United States. Most of these reservations were established decades ago to support various national defense and national security missions. The large size of these reservations is due primarily for the need for a large buffer area between communities and reservation operations. As a consequence, only a small percentage of many of these facilities are actively used. In many cases this has resulted in intact habitats that have been protected from the development pressures often seen in adjacent areas. There are numerous examples of rare species occurring and thriving on these reservations, whereas they have been extirpated from the surrounding areas.

Lawrence Livermore National Laboratory's (LLNL) Site 300 is just such an example. Site 300 is a Department of Energy facility established in the early 1950's to conduct high explosives testing in support of LLNL's weapons program (Ferry et al. 1999). The 11 mi² (2,849 ha) site is located in the eastern Altamont Hills about 13 miles southeast of the main LLNL site in Livermore, California and 8.5 miles southwest of Tracy, California. This area has a Mediterranean climate, with the majority of the precipitation occurring as rain between November and March. The site is composed of rolling hills of primarily annual exotic and native perennial grasslands, with some oak woodland habitat in the southwestern portion of the site. Riparian and wetland habitat is limited to isolated springs scattered throughout the site. The site is surrounded primarily by cattle ranches, as well as a State Vehicular Recreation Area used for off-road motorcycle riding. There is a proposed residential development on the northeast and western boundary.

The high-explosives testing conducted at Site 300 is done on outside firing tables established in the northern, higher elevation (1,750 ft) portion of the site. Various processing and support facilities are located in the lower elevation (500 ft) southern portion of the site. Less than 5% of the site is developed (DOE 2005). Annual spring burns are conducted in the northern portion of the site to reduce the threat of grassland wildfire due to firing table activities during the dry summer months. These burns are typically conducted between late May and late June, rarely extending into early July. Figure 1 shows the Site 300 fire frequency for the past 29 years. Fire trail grading is also conducted to provide access to and control of the annual burns.

The large, protected undeveloped area in addition to the programmatic activities of annual spring burns and fire trail grading has resulted in a unique grassland habitat at Site 300 when compared to surrounding lands. The severe selective pressure of the annual burns has resulted in large stands of native perennial bunch grass dominated by *Poa secunda* J.S.Presl (DOE 2005). Eight special status plant species are known to occur at the site, four of which are actively managed (Paterson et al. 2005). These four species are *Amsinckia grandiflora* (Gray) Kleebl. Ex Greene (Boraginaceae, federally endangered), *Blepharizonia plumosa* (Kellogg) E. Greene (Asteraceae, CNPS List 1B), *Eschscholtzia rhombipetala* E. Greene (Papaveraceae, CNPS List 1B), and *California macrophyllum* (Hook. & Arn.) J.J. Aldasoro, C. Navarro, P. Vargas, L. Saez and C. Aedo (Geraniaceae, CNPS List 1B). All are spring flowering annuals with the exception of *B. plumosa*, which is a fall flowering annual. *A. grandiflora* and *E. rhombipetala* occur in areas not routinely burned, where as *B. plumosa* and *C. macrophyllum* occur in areas undergoing annual burning. In this essay, we compare and contrast the success of the management and restoration of *A. grandiflora* with *B. plumosa*, and the degree with which each is taking advantage of the unique characteristics of Site 300.

MANAGING AMSINCKIA GRANDIFLORA

Amsinckia grandiflora is one of 15 species in the genus recognized by Ray and Chisaki (1957a, 1957b). As a member of the California winter annual grassland, *Amsinckia* germinates with the onset of fall or winter rains, grows vegetatively throughout the winter, flowers in early spring, and sets seed and dies before the summer drought (Heady 1990). It is currently known from only three natural populations, two of which occur at Site 300 (Fig 2), the third occurring on private ranchland adjacent to Site 300. Of these, only the Site 300 Drop Tower native population has had plants observed in recent years. The Site 300 Draney Canyon native population was likely extirpated in 1997 during heavy winter rains, which resulted in erosion of the hillside containing the population. The Carnegie Canyon native population adjacent to Site 300 has been under severe cattle grazing pressure, and plants have not been observed in recent years (Paterson et al. 2008).

Amsinckia grandiflora is one of four rare heterostylous species within the genus *Amsinckia* that have highly restricted distributions from which the more weedy homostylous congeners are thought to have evolved (Ray and Chisaki 1957a, b; Shoen et al. 1997). The historic distribution of *A. grandiflora* (first recorded in the 1800s) extended 72 km northward from its current location at and adjacent to Site 300. Potential extrinsic limitations on the species include the invasion of non-natives species, livestock grazing, fire suppression, and land conversion (Pavlik et al. 1993, USFWS 1997, Carlsen et al. 2000). Possible intrinsic limitations on *A. grandiflora* could result from its breeding system, or from genetic homogeneity as a result of low population density (Stebbins 1942, Hamilton and Mitchell-Olds 1994). Ornduff (1976) specifically proposed heterostyly as the main factor contributing to *A. grandiflora*'s low seed set, and further suggested this species was naturally going extinct. Pantone et al. (1995) found that dynamic

fitness component compensation (i.e., fewer seeds per flower compensated by more flowers per inflorescence) did not occur within either *A. grandiflora* or the widespread homostyle *A. menziessi* var. *intermedia* (Fischer & C. Meyer) Ganders, in an outdoor common garden experiment in an exotic environment more than 800 km from the native location in Texas, USA. Carlsen et al. (2002) found that in the greenhouse, *A. grandiflora* did balance low floral seed set (seeds per flower) with increased floral output (flowers/plant) and a greater number of flowers per inflorescence. In addition, seed set from active hand-pollinated self-, intra- and inter-morph pollinations was high, indicating that the cryptic self-incompatibility system is more of a result of the physical separation of stigma and style, rather than a true self-incompatibility.

However, in the field, *A. grandiflora* floral output was only slightly greater than the widespread homostylous congener *A. tessellata* A. Gray, and did not fully balance the lower floral seed set (Carlsen et al. 2002), suggesting environmental factors were at least partially responsible for the reduced seed output, and by inference, the decline in *A. grandiflora* populations. The focus of management activities at Site 300 on *A. grandiflora* has been on understanding and managing these environmental factors.

To better understand the environmental factors controlling *A. grandiflora*, an experimental population was established near the native Drop Tower population in 1991. This original experimental population is known as the flashing population (FL) due to the buried metal flashing around the population installed for rodent control. Initial experiments on this population revealed *A. grandiflora* inflorescence production to be higher in intermediate densities of *Poa secunda* when compared to similar densities of annual exotic grasses (Fig 3, Carlsen et al. 2000). These results were consistent with the results of Pavlik et al. (1993) obtained at an experimental

population established at Lougher Ridge near Antioch, California, who also showed controlling annual grass densities resulted in improved reproductive success of *A. grandiflora*.

As annual controlled burns are routinely conducted at Site 300 and have resulted in large stands of *Poa secunda*, the use of controlled burns as a habitat management tool for *A. grandiflora* has been a recent focus. A second experimental population, known as the fire frequency (FF) population was established in 1998 (Paterson et al. 2005) adjacent to the original FL experimental population. The FF population consists of twenty plots initially restored with equal densities of *P. secunda* plugs obtained from adjacent grasslands and divided between four treatments; 1) control plots (no controlled burns after initial plot establishment), 2) low frequency controlled burns (every 5 years), 3) medium frequency controlled burns (every three years) and high frequency controlled burns (every year). A wildfire in 2005 burned all plots, including the control plots. Figure 4 shows the number of *P. secunda* plants within plots to be greatest with higher frequency of burning (Paterson et al. 2008). However, Table 1 shows *A. grandiflora* densities to be highest in control plots. This may be in part due to an interaction between seed predation and burning. *A. grandiflora* seed predation can be highly variable between years in unburned plots (Fig 5a, Espeland et al. 2005). Burned plots are further exposed to predators, and can have a very high predation rate (Fig 5b).

In addition to investigating the use of controlled burns to increase *Poa secunda* density and improve *A. grandiflora* success, grass selective herbicide has also been used on the native Drop Tower population in an attempt to reduce annual grass cover. In the early 1990's, the number of *A. grandiflora* individuals had dropped to alarmingly low levels. Based on early results later reported in Pavlik et al. (1993) suggesting controlling annual grass cover was essential to the survival of *A. grandiflora*, a dilute solution of grass selective herbicide was used on the native

Drop Tower population. Initially the population responded favorably (Fig 6). However, beginning in 1999, this population again began to severely decline. This was also observed in the Site 300 experimental populations (Fig 7) as well as the Lougher Ridge experimental population. Attempts to correlate this decline with annual rainfall, either with the current or previous year, have not been successful.

MANAGING BLEPHARIZONIA PLUMOSA

Blepharizonia plumosa (the big tarplant) is a late-flowering annual member of the tarplant subtribe *Madiinae* in the Asteraceae family (Gregory et al. 2001). This subtribe includes *Hemizonia*, *Madia*, and *Calycadenia* as well as *Blepharizonia*. The flowering period for these late-flowering forbs starts in late July or early August and can extend into November. Because of their late-flowering period, summer forbs spend much of their lifetime in the harsh California summer drought. As a result, species such as *B. plumosa* are dependent on the soil moisture remaining after the spring-flowering annual flora has senesced. *Blepharizonia plumosa* populations have been identified in the interior Coast Range in Alameda, Contra Costa, San Joaquin, Stanislaus and Solano counties (California Department of Fish and Game 2009). *Blepharizonia plumosa* was identified at Site 300 during habitat surveys in 1996 (Gregory et al. 2001). In addition, the more common big tarplant, *B. laxa*, was also identified at Site 300. Although rare outside of Site 300, *B. plumosa* is quite common at Site 300, particularly in areas that are routinely burned (Fig 8). *Blepharizonia laxa* is uncommon at Site 300, occurring in both unburned and burned areas.

The occurrence of *B. plumosa* in areas routinely burned at Site 300 is noteworthy, as these burns typically occur in the late May-early June time period, a time when *B. plumosa* is in a

small, vegetative stage. Annual surveys have shown *B. plumosa* to take advantage of the patchiness of the burns. Table 2 shows three years of survivorship results for *B. plumosa* (Paterson et al. 2005). Overall post-burn survivorship represents the percentage of marked seedlings that survived to flowering, regardless of whether they occurred in a burned or unburned patch. Survivorship in burned areas represents the percentage of marked seedlings observed surviving immediately after the spring burn in patches that were clearly burned. Survivorship in unburned areas represents the percentage of original marked seedlings observed surviving immediately after the spring burn in patches that were clearly unburned. Finally, survivorship post-burn to flowering represents the percentage of marked seedlings observed surviving immediately after spring burn that went on to survive to flowering. *Blepharizonia plumosa* seedlings in burned patches suffered high mortality as a result of direct contact with the fire. Seedlings in unburned patches had a very high survivorship rate immediately post-burn, and all those seedlings that survived post-burn had a very high rate of survivorship to flowering.

In addition to taking advantage of the patchiness of the burn in the current growing season, *B. plumosa* also appears to take advantage of the reduced competition resulting from the burn in subsequent years. Figure 9 shows the distribution of *B. plumosa* with respect to the annual controlled burn area in 2001, a year in which a larger number of acres were burned than normal, and with fairly high intensity. *Blepharizonia plumosa* populations were essentially restricted to roadsides and dirt fire trails. The following year, 2002, *B. plumosa* populations expanded into these previously burned areas that were not again burned in the spring of 2002.

This suggested that *B. plumosa* seedling recruitment was higher in areas that were burned the previous year, but not burned during the current growing season. To test this, a series of transects were established in 2005 in an area that had not been burned in five years and had seen

a decline in *B. plumosa* numbers (Fig 10). Seedlings were counted along these transect in the spring of 2005. All transects were then subsequently burned. Seedlings were again counted in the spring of 2006 (Table 3). Seedling recruitment declined in one transect, was essentially unchanged in two transects, and increased in two transects. Results may have been affected by the poor performance of *B. plumosa* site-wide in 2006 (Fig 11). While a paired t-test comparing the number of pre-burn seedlings to post-burn seedlings was not significant ($p=0.39$), the results suggest seedling recruitment may be enhanced by burning the year previous to the current growing season.

As a late-flowering forb, *B. plumosa* populations are extremely sensitive to soil moisture availability. The area of *B. plumosa* populations at Site 300 is highly correlated with the amount of rainfall during the winter previous to the fall census (Fig 11).

DISCUSSION

Amsinckia grandiflora has long been a subject of intense study by botanists and ecologists due to its unique breeding system and extreme rarity. However, even with such a focus, the species continues to decline. *Amsinckia grandiflora* appears to have very narrow environmental requirements, which to date have not been well elucidated. This, along with the inherent limitations of its heterostylous breeding system, appears to be working against the continued survival of this species.

Amsinckia grandiflora has been negatively impacted by the conversion of its habitat from native perennial grasslands to exotic annual grasslands (Pavlik et al. 1993, Carlsen et al. 2000). However, control of exotic grass cover is not sufficient to ensure the continued survival of this species. Several limitations to the use of controlled burns to establish native perennial grasslands

as habitat for *A. grandiflora* have been identified. First, *A. grandiflora* seeds (also known as nutlets) are relatively large (up to 5 mg, Carlsen et al. 2002). This may limit dispersal, with most seeds falling near the maternal plants. These seeds are then potentially exposed to the direct effects of fire from the late-spring controlled burns that occur immediately after seed rain.

Amsinckia grandiflora seeds do not tolerate high temperatures (unpublished data) and thus would not be expected to survive. Those seeds that do escape the direct effects of the fire are at high risk of predation in the area exposed by the controlled burn. Finally, the low number of *A. grandiflora* plants that occur outside the area of the controlled burn, along with the limited seed dispersal potential, limits the source of seeds that could take advantage of the burned area in the following growing season.

The use of grass-selective herbicide to control annual grass cover has also been shown to be insufficient to maintain *A. grandiflora* populations. Other unknown environmental factors appear to be at work. The size of *A. grandiflora* populations do not appear to be directly correlated with rainfall patterns, although an indirect correlation (and perhaps a delayed one) cannot be ruled out. In recent years, damping of the hypocotyl, resulting in an extremely thin hypocotyl between the root system and the main stem has been increasingly observed. The resulting plants are small and produce few flowers. Fungal or other soil factors may also impact the success of *A. grandiflora*, as well as an interaction between soil conditions and climate.

This species has benefited from occurring on a Department of Energy reservation, where substantial financial resources have been made available to investigate the environmental factors responsible for the decline of the species in an attempt to develop management strategies. Currently, *A. grandiflora* exists primarily in the experimental population at Site 300, where the

population is periodically reseeded and thus individuals are maintained. Without the continued management of this experimental population, the species is likely to go extinct.

In contrast, *Blepharizonia plumosa* appears to have a type of breeding system and relatively straightforward environmental requirements that allow it to take advantage of the unique characteristics of Site 300. *Blepharizonia plumosa* is in a vegetative stage at the time of the annual spring burns. While these plants do not survive direct contact with the fire, those plants that escape the fire in unburned patches grow very large, and produce many seeds (also known as achenes). These seeds are small and possess a large plumose pappus, which aids in wind dispersal (Gregory et al. 2001). Seeds are dispersed in the fall, and thus can readily take advantage of areas that were burned the previous spring. Seeds produced by disk flowers readily germinate with the onset of winter rains, while seeds from ray flowers possess a dormancy of unknown length (Gregory et al. 2001). By over-wintering prior to the spring burns, ray flower seeds have an opportunity to become covered by a thin layer of soil, which could protect them from the direct effects of the fire.

Like *A. grandiflora*, *B. plumosa* benefits from areas of reduced annual grass cover. Unlike *A. grandiflora*, *B. plumosa* can take advantage of the reduced annual grass cover afforded by the annual spring burns conducted at the site. *Blepharizonia plumosa* responds best in areas that are not burned every year, but at a more intermediate (every 3 to 5 yr) frequency. The population is large enough at Site 300 that it exhibits metapopulation dynamics, with current year populations providing the seed source that can take advantage of habitat enhanced or created by the controlled burn. In years when large areas of Site 300 are burned with a high degree of fire intensity, fire trails (unpaved dirt roads) provide refugia for *B. plumosa* plants, which in turn provide the seed source for the next year's population.

The programmatic need to conduct annual spring burns is likely directly responsible for the success of *B. plumosa* at Site 300. The lack of such activities and the resulting large-scale land conversion is at least partially responsible for the decline of this species outside of Site 300. This implies that should annual burns no longer be required at Site 300, *B. plumosa* is likely to suffer a similar decline as seen elsewhere. Controlled burns should continue to be used as a management tool to maintain the large population of *B. plumosa* at Site 300. In addition, activities to restore this species elsewhere should consider a similar use of controlled burns.

The relative success of restoring and managing these two species shows the importance of understanding, and taking advantage of, the interaction between the species' inherent biology and its specific environmental requirements. This is easier said than done. Determining this interaction for *Blepharizonia plumosa* was relatively straightforward. Determining this for *A. grandiflora* has been an act in frustration. But by evaluating the breeding system and the attempted management tools, it was possible to hypothesize why we have so far failed with one species, while we have succeeded with another. Future restoration attempts for similar species should conduct similar evaluations.

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LITERATURE CITED

CALIFORNIA DEPARTMENT OF FISH AND GAME. 2009. California Natural Diversity Database. California Department of Fish and Game, Biogeographic Data Branch, Sacramento, CA, USA. Government Version - Dated April 4, 2009.

CARLSEN, T. M., B. PAVLIK AND J. MENKE. 2000. Reducing competitive suppression of a rare annual forb by restoring native California perennial grasslands. *Restoration Ecology* 8(1):11-29.

CARLSEN, T. M., E. K. ESPELAND AND B. M. PAVLIK. 2002. Reproductive ecology and persistence of an endangered plant. *Biodiversity and Conservation* 11:1247-1268.

FERRY, L., R. FERRY, W. ISHERWOOD, R. WOODWARD, T. CARLSEN, Z. DEMIR, R. QADIR, AND M. DRESEN. 1999. Final Site-Wide Feasibility Study for Lawrence Livermore National Laboratory Site 300. Lawrence Livermore National Laboratory, Livermore, CA, USA. UCRL-AR-132609.

GREGORY, S. D., E. K. ESPELAND AND T. M. CARLSEN. 2001. Demography and population biology of a rare tarplant, *Bleparizonia plumosa*, (Asteraceae) a California summer annual forb. *Madrono* 48(4):272-2001.

HEADY, H. F. 1990. Valley grassland. Pages 491–514 in M. B. Barbour and J. Major, editors. Terrestrial vegetation of California. California Native Plant Society, Sacramento.

ORNDUFF, R. 1976. The reproductive system of *Amsinckia grandiflora*, a distylous species. Systematic Botany 1:57-66.

PANTONE, D. J., B. M. PAVLIK AND R. B. KELLY. 1995. The reproductive attributes of an endangered plant as compared to a weedy congener. Biological Conservation 71:305-311.

PATERSON, L., E. ESPELAND AND T. CARLSEN. 2005. Rare Plant Restoration and Monitoring at Lawrence Livermore National Laboratory Site 300 Project Progress Report Fiscal Years 2003 & 2004 October 2002–October 2004. Lawrence Livermore National Laboratory, Livermore, CA, USA. UCRL-AR-142408-03/04.

PATERSON, L., T. ALFARO, E. ESPELAND AND T. CARLSEN. 2008. Rare Plant Restoration and Monitoring at Lawrence Livermore National Laboratory Site 300 Project Progress Report Fiscal Years 2005 & 2006. Lawrence Livermore National Laboratory, Livermore, CA, USA.

RAY, P. M. AND H. F. CHISAKI. 1957a. Studies of *Amsinckia*. I. A synopsis of the genus, with a study of heterostyly in it. American Journal of Botany. 44:524-536.

RAY, P. M. AND H. F. CHISAKI. 1957b. Studies of *Amsinckia*. II. Relationships among primitive species. *American Journal of Botany*. 44:537-544.

SHOEN, D. J., M. O. JOHNSTON, A. M. L'HEREUX AND J. V. MARSOLAIS. 1997. Evolutionary history of the mating system of *Amsinckia* (Boraginaceae). *Evolution* 51:1090-1099.

PAVLIK, B. M., D. L. NICKRENT AND A. M. HOWALD. 1993. The recovery of an endangered plant. I. Creating a new population of *Amsinckia grandiflora*. *Conservation Biology* 7:510-526.

U.S. DEPARTMENT OF ENERGY (DOE) NATIONAL NUCLEAR SECURITY ADMINISTRATION. 2005. Final Site-wide Environmental Impact Statement for the Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management of Programmatic Environmental Impact Statement (DOE/EIS-0348 and DOE/EIS-0236-S3).

U.S. FISH AND WILDLIFE SERVICE (USFWS). 1997. Large-flowered fiddleneck. *Amsinckia grandiflora* Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon. 44 pp.

TABLES

Table 1. *Amsinckia grandiflora* density in fire frequency plots.

Values are means \pm one standard deviation.

	Fire frequency		
	Control	Low & Medium	High
	N = 5	N = 10	N = 5
2006	1.25 \pm 2.89	0.50 \pm 1.77	0
2005	8.00 \pm 8.91	3.00 \pm 2.09	0.70 \pm 1.57
2004	2.2 \pm 2.0	0.4 \pm 0.5	0
2003	2.0 \pm 3.5	3.2 \pm 2.9	1.6 \pm 1.1
2002	5.6 \pm 4.8	1.0 \pm 1.7	2.6 \pm 3.7

Control=No spring burning; Low=spring burning every 5 years;

Medium=spring burning every three years; High=spring burning every year;

N=number of plots

Table 2. *Blepharizonia plumosa* and *B. laxa* survivorship in three populations undergoing annual spring burns.

Year	Population	Species	N	Survivorship			
				Overall	Burned	Unburned	Post-burn to
				Post-burn ^a	areas ^b	areas ^c	flowering ^d
				(%)	(%)	(%)	(%)
2000	1	<i>B. plumosa</i>	104	20	8	76	59
	2	<i>B. plumosa</i>	170	1	0	50	44
2001	1	<i>B. plumosa</i>	100	0	0	NA	0
	2	<i>B. plumosa</i>	146	32	0	96	52
	3	<i>B. laxa</i>	110	39	0	40	77
2002	1	<i>B. plumosa</i>	97	3	3	NA	44
	2	<i>B. plumosa</i>	100	0	0	NA	90
	3	<i>B. laxa</i>	99	33	5	77	26

^a Overall post-burn survivorship represents the percentage of seedlings marked surviving to flowering, regardless of whether in a burned or unburned patch

^b Survivorship in burned areas represents the percentage of marked seedlings surviving immediately after spring burn in burned patches

^c Survivorship in unburned areas represents the percentage of original marked seedlings surviving immediately after spring burn in unburned patches;

^d Survivorship post-burn to flowering represents the percentage of seedlings surviving immediately after spring burn surviving to flowering.

N=number of marked plants

Table 3. Number of *B. plumosa* seedlings prior to the 2005 spring burn compared to one year post-burn (2006).

Transect	Pre-2005	2006
	Spring burn	
1	76	22
2	30	28
3	30	34
4	8	80
5	6	156

Number of seedlings pre- and post-burn not significant at $p=0.39$ using a paired t-test; no spring burn was conducted on the transects in 2006

FIGURES

Figure 1. Frequency of annual spring burns at Site 300 for the past 29 years.

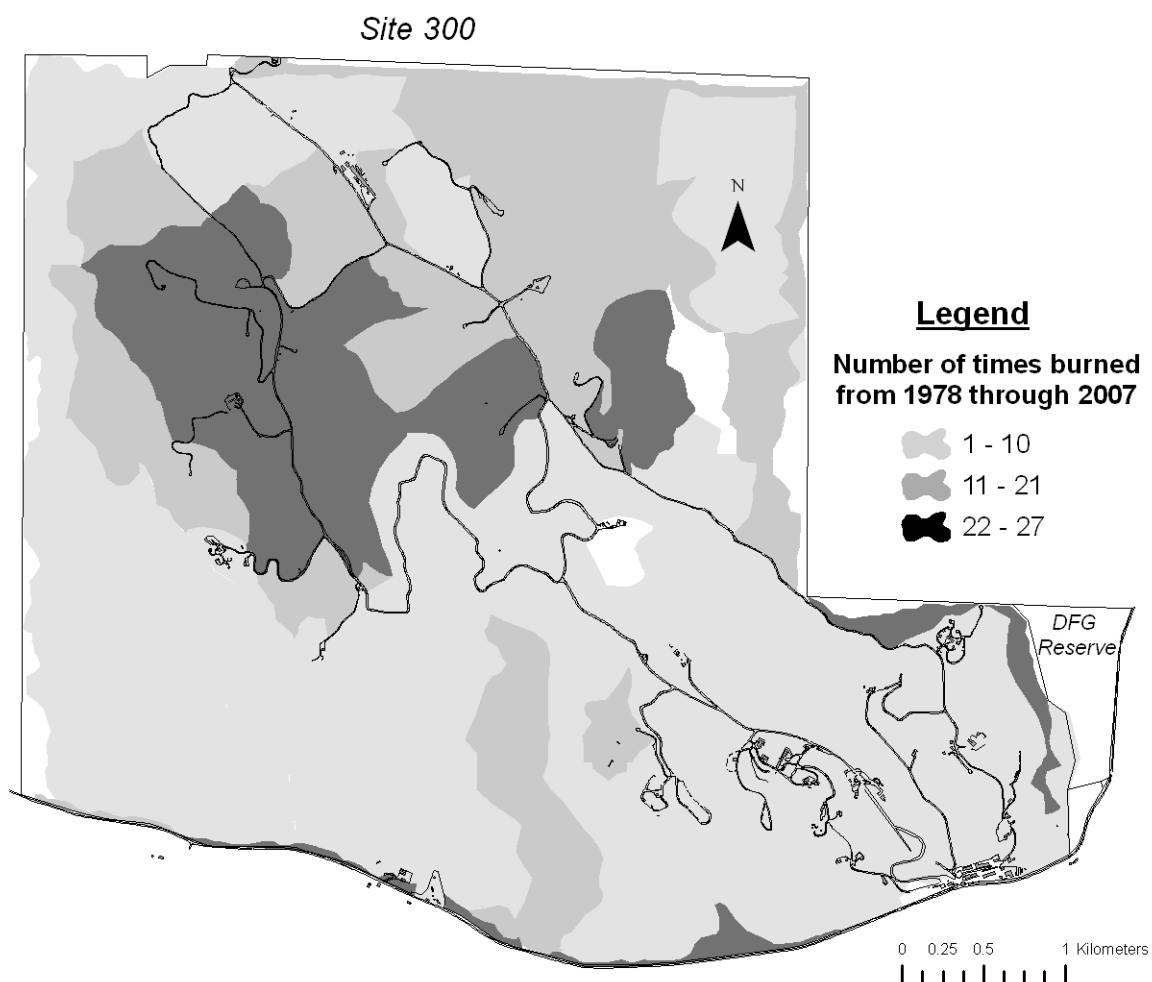
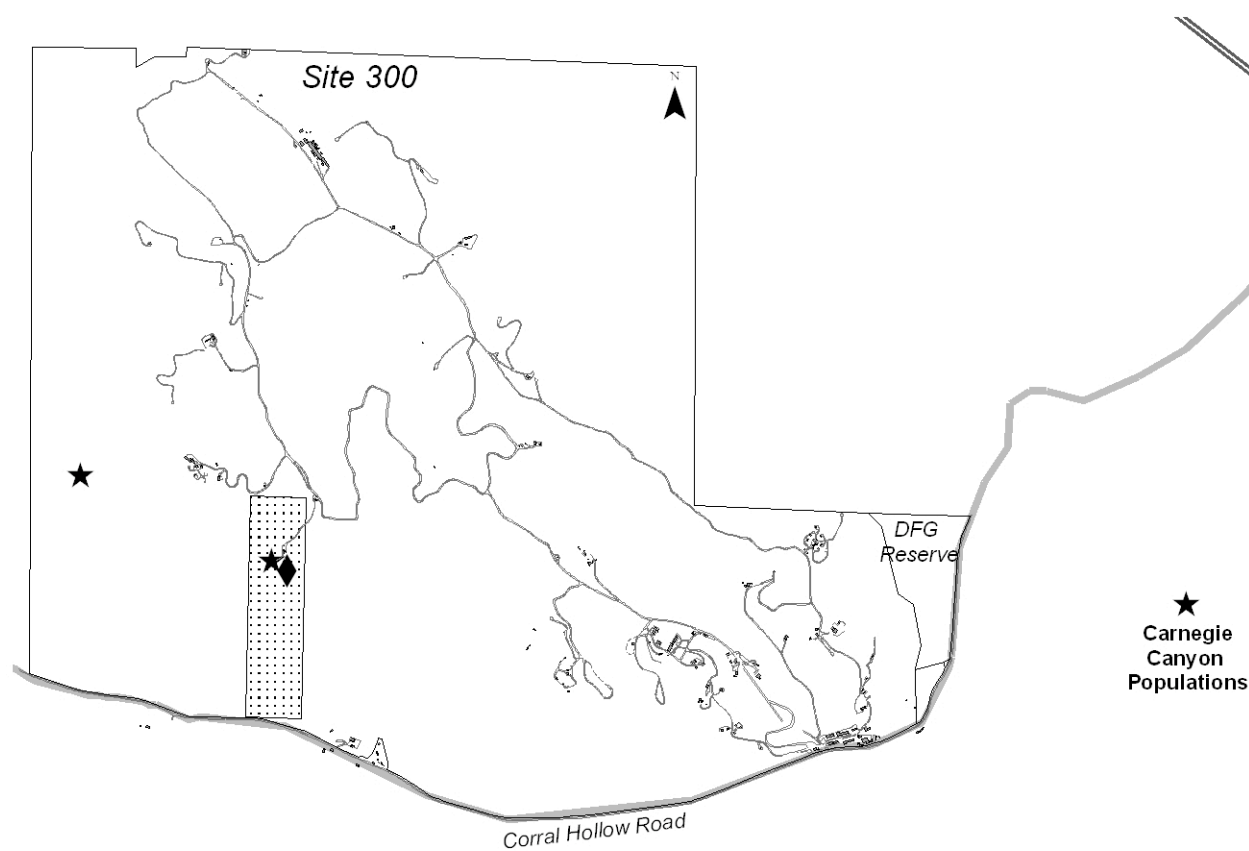





Figure 2. Distribution of *Amsinckia grandiflora* at Site 300.**Legend**

-  Large-flowered fiddleneck critical habitat
-  Large-flowered fiddleneck native population
-  Large-flowered fiddleneck experimental population

0 0.25 0.5 1 Kilometers



Figure 3. Relationship of *Amsinckia grandiflora* total inflorescence number per plot (as measured on 12 April 1994) to final dry grass biomass (collected on 1 May 1994), showing predicted and 95% confidence intervals of the mean; *Poa* = native *Poa secunda* perennial bunch grass; *Annual grass* = introduced annual grasses (from Carlsen et al. 2000).

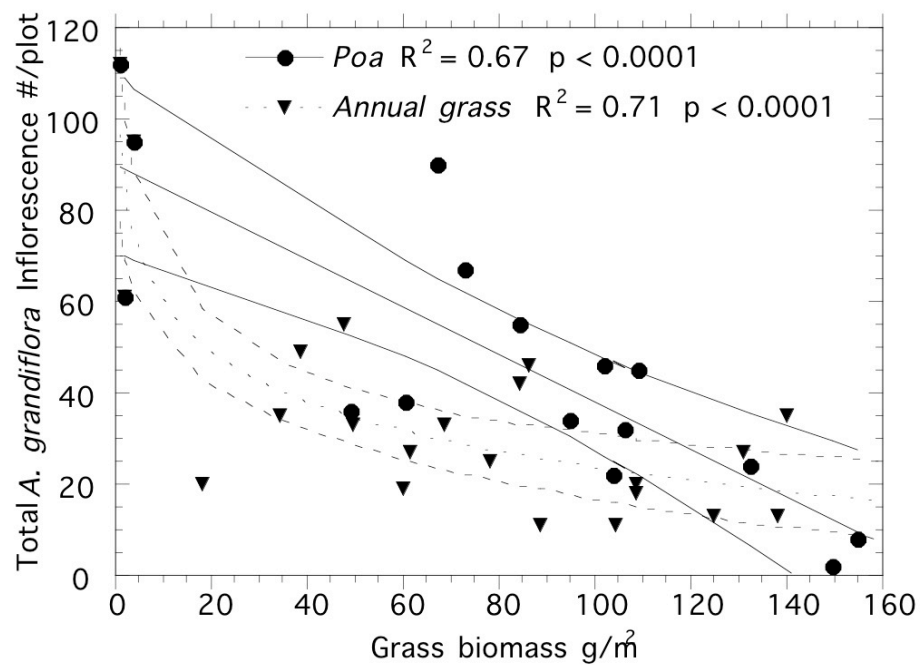


Figure 4. Number of *Poa secunda* plants per plot for various fire frequencies. Control=no spring burning, Low=plots burned every 5 years, Medium=plots burned every 3 years, High=plots burned every year; N=5 for all treatments.

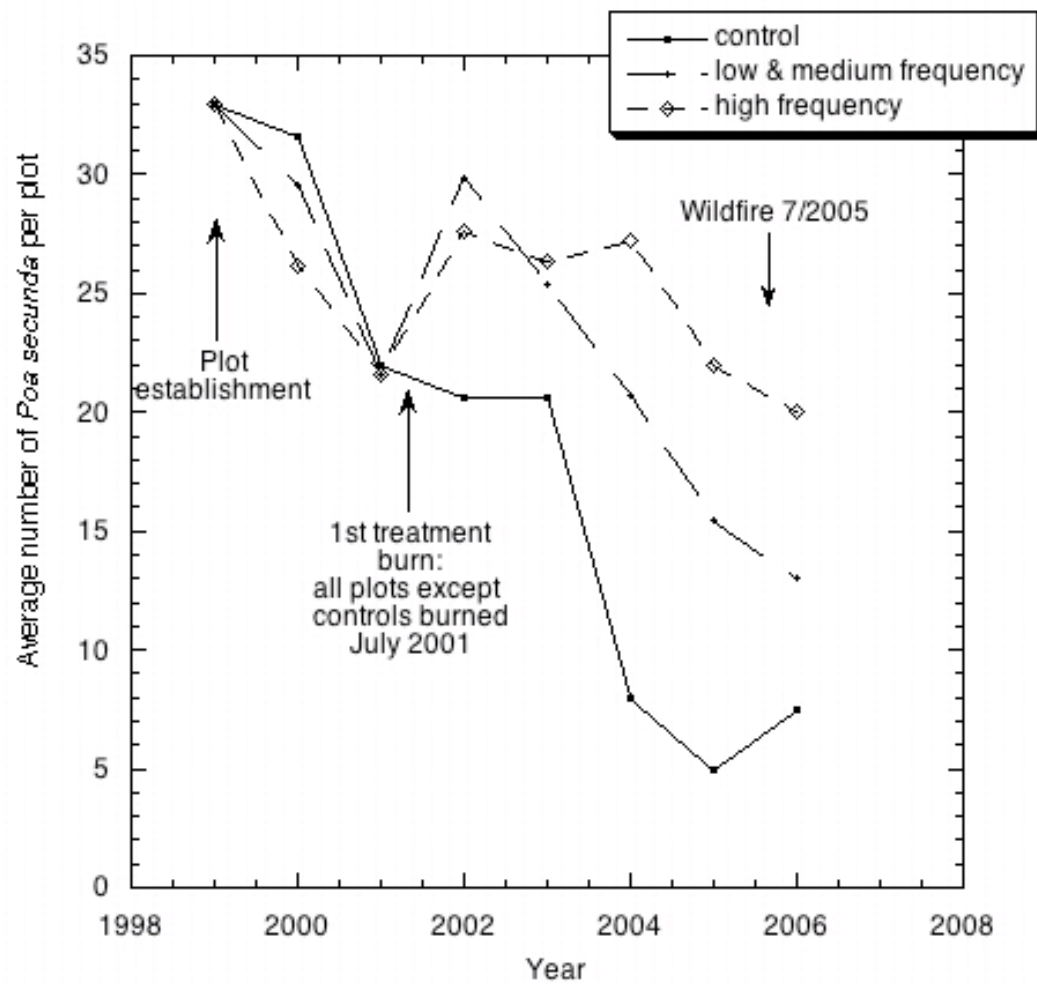


Figure 5. Mean percent predation of *Amsinckia grandiflora* seeds over a three week period in late spring/early summer, (a) mean percent predation in unburned plots by year; (b) mean percent predation in unburned compared to burned plots in 2001 and 2002, ** = significant at $p < 0.05$ using Mann-Whitney U test; error bars are variance; adapted from Table 1 in Espeland et al. 2005.

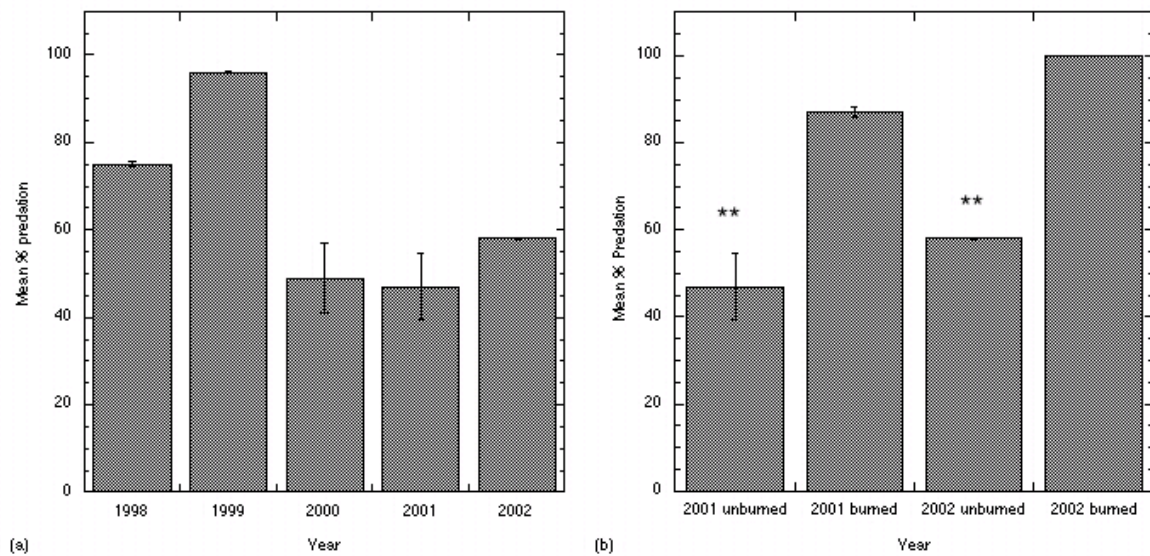


Figure 6. *Amsinckia grandiflora* native Drop Tower population census results and management actions (from Paterson et al. 2008).

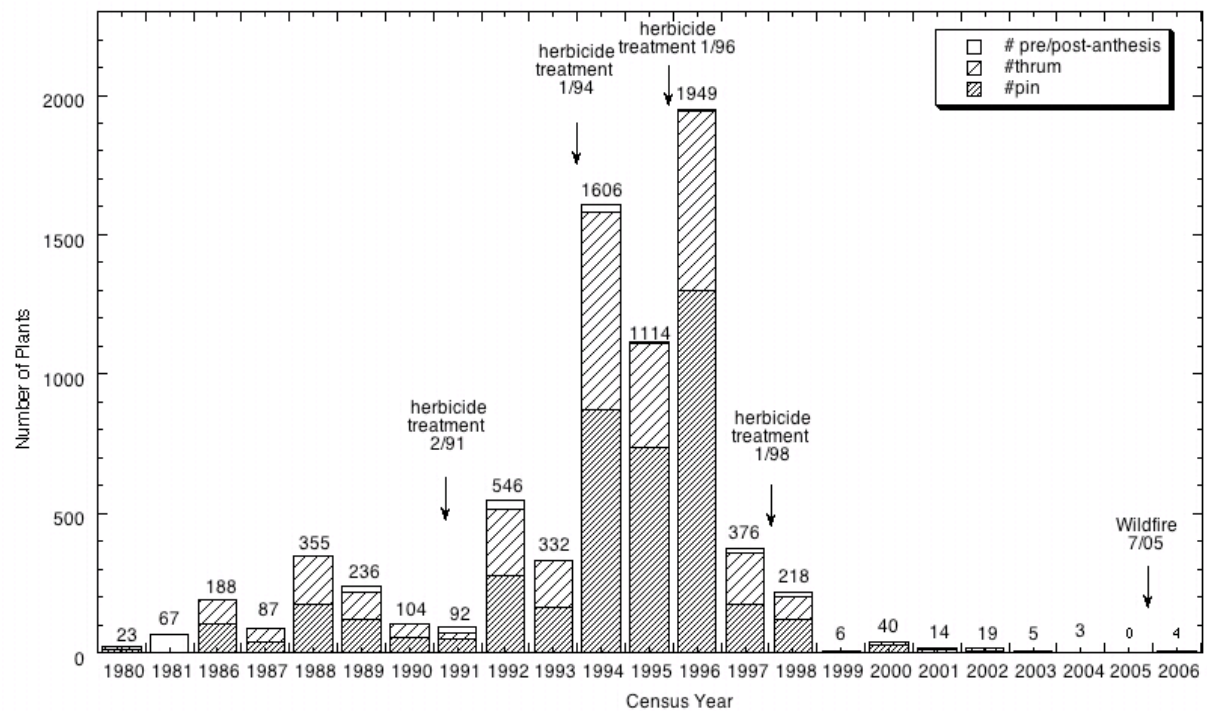


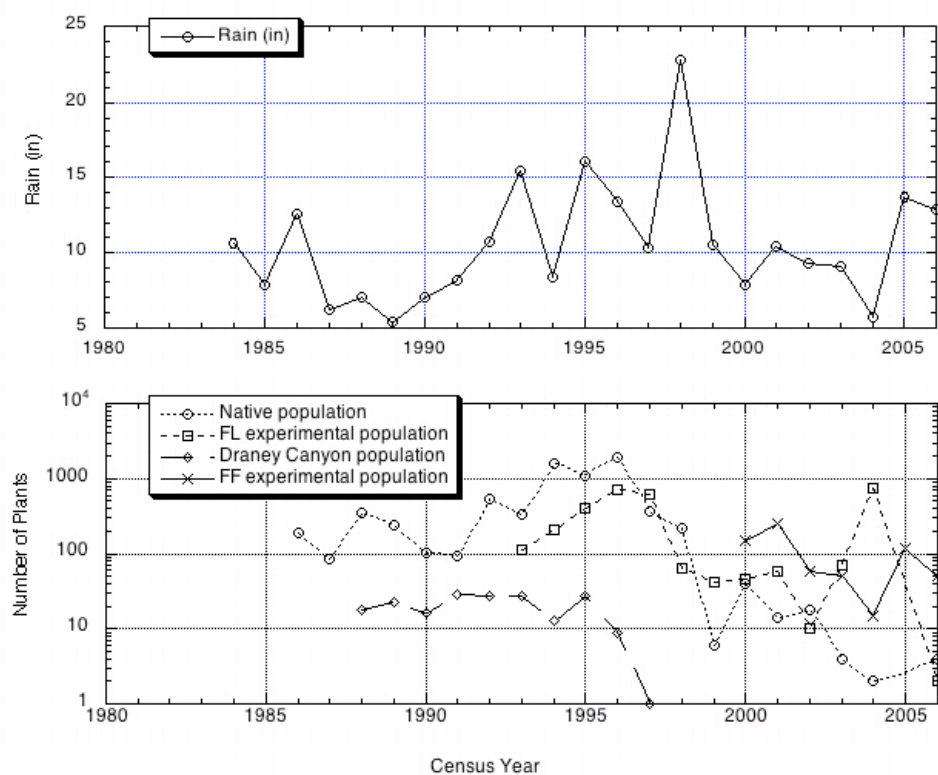
Figure 7. Relationship between *A. grandiflora* census results and rainfall.

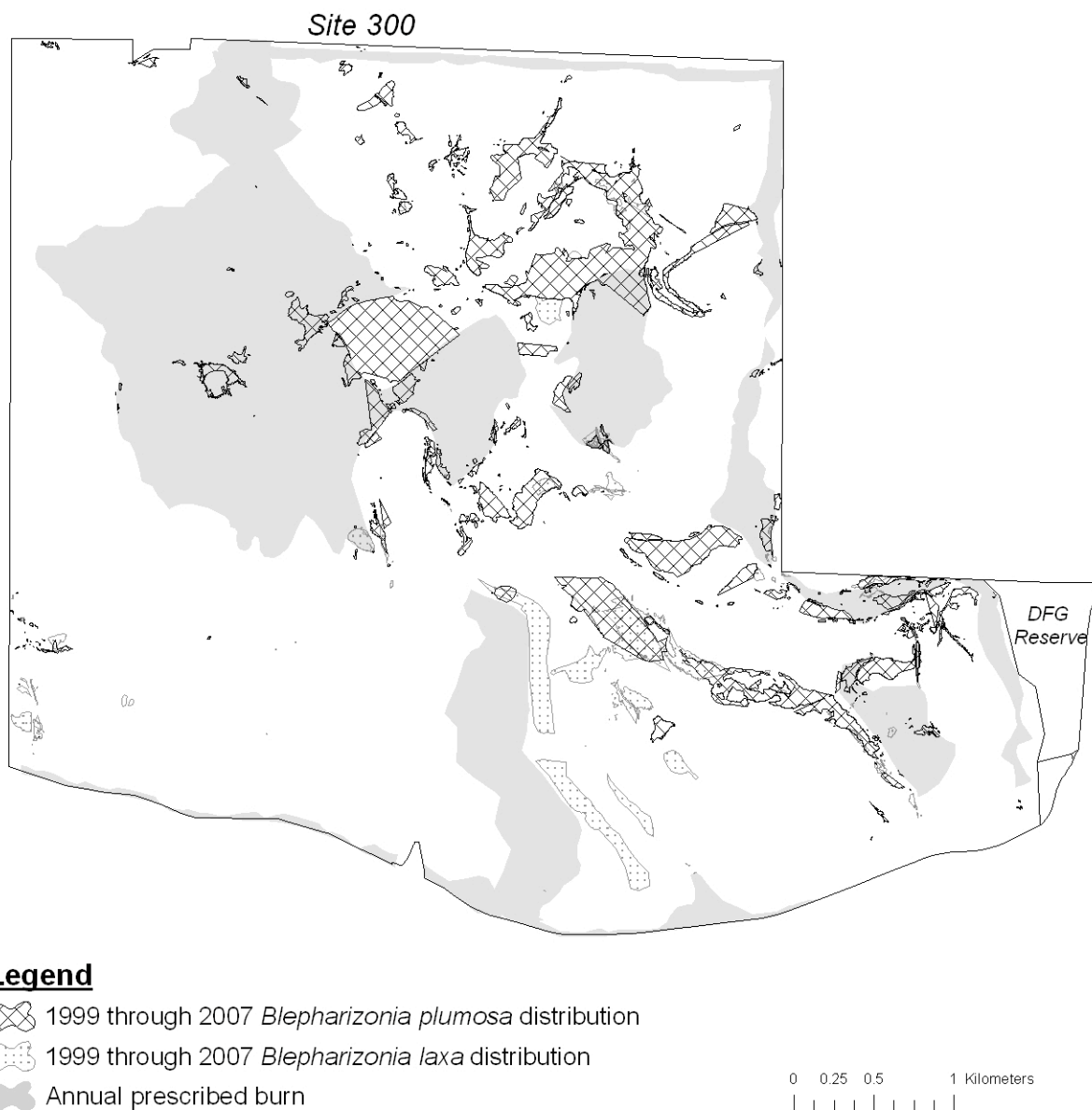
Figure 8. Distribution of *Blepharizonia plumosa* and *B. laxa* at Site 300.

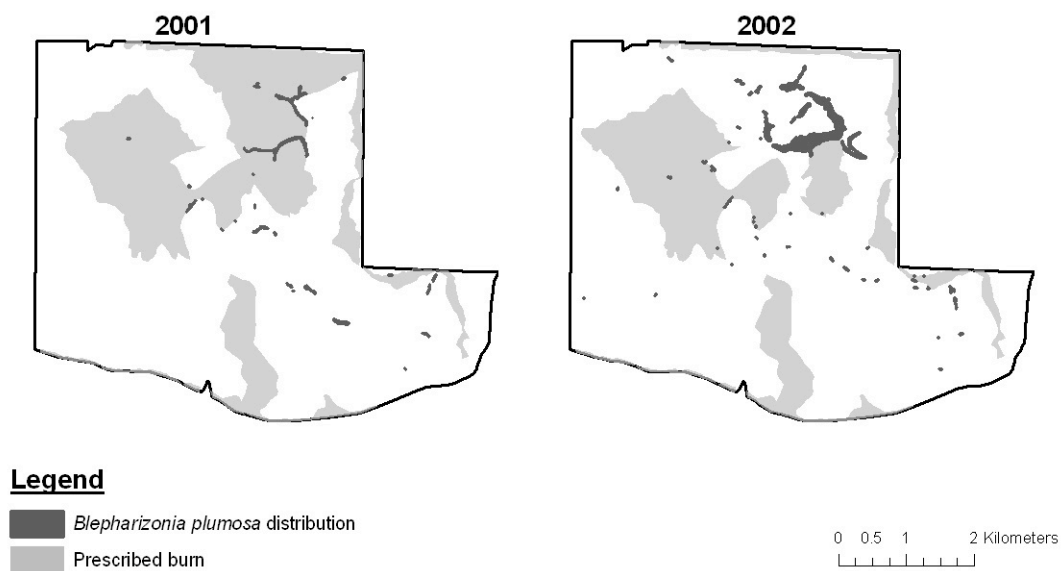
Figure 9. Relationship between *B. plumosa* distribution and spring controlled burns.

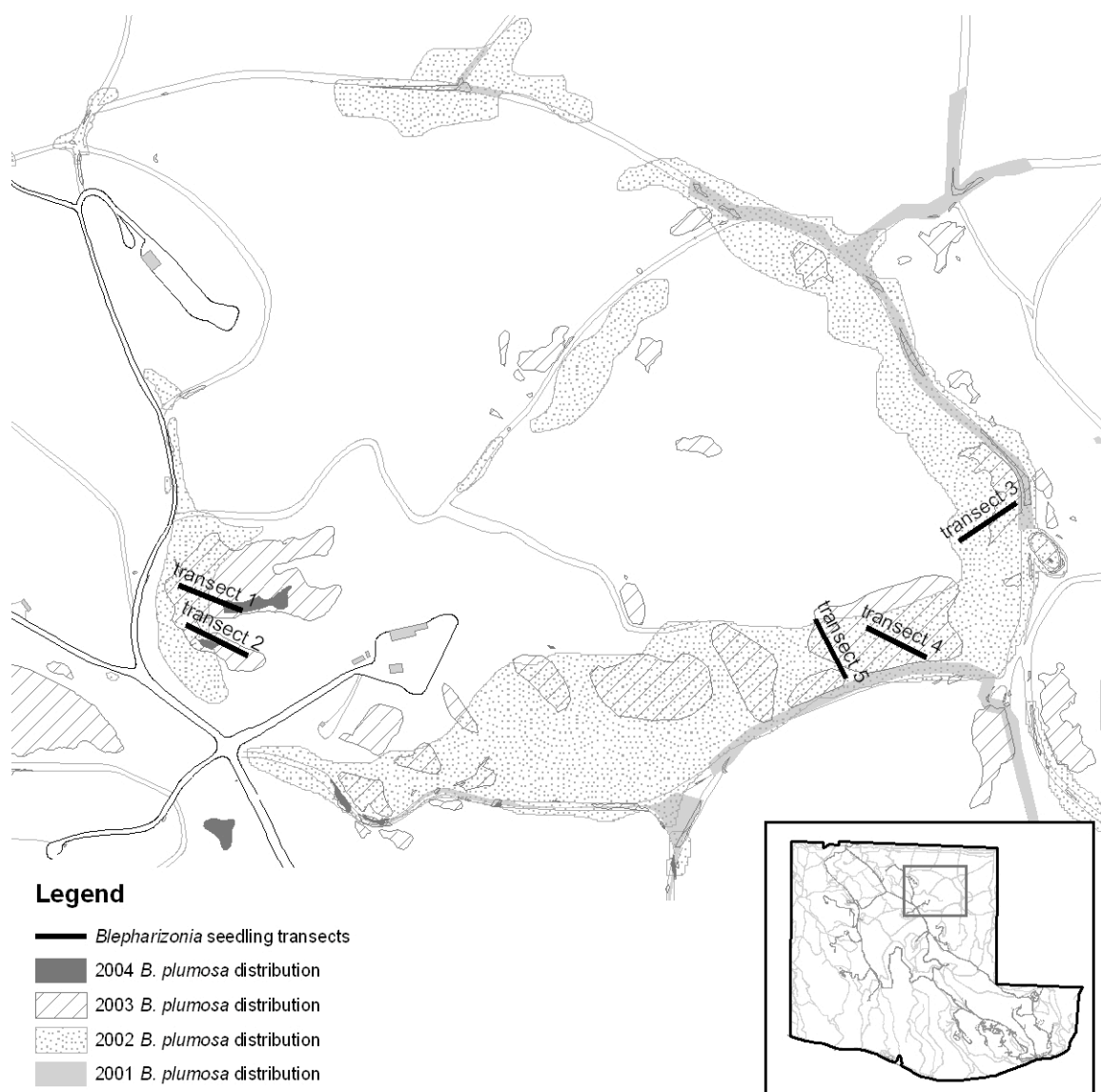
Figure 10. Locations of *B. plumosa* seedling recruitment transects.

Figure 11. Relationship between *B. plumosa* distribution and rainfall.